Historical Problem Areas
Lessons Learned

N91-28242

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- Long Life Spacecraft Propulsion Systems

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- Launch Vehicles & Reusable Systems

Historical Problem Areas
Introductory Comments

- RELIABILITY Not Efficiency Is More Critical for Future Long Life/Reusable Propulsion Systems
  - Can Plan for Low Efficiency But Not UNPREDICTABLE Performance
  - Orbital Maintenance Is A Total Unknown - Tremendous Design/Logistics Implications
  - Space Shuttle Is BEST Reusable/Long Life System Available - Maintenance Level Unacceptable for Orbital Use

Historical Problem Areas
Introductory Comments

- Primary RELIABILITY Deficiencies
  - MATERIALS - Propellant, Thermal, Wear, Contamination, Space Environment Compatibility
  - SIMPLE Designs
    - Commonality, Integrated Systems, Orbital Maintenance - Often Impact Design Simplicity
  - MATURE Hardware - Properly Tested and Analyzed Prior to Operational Commitment
  - Firm Definition of Design REQUIREMENTS and Technology Assessment Before Design Commitment
    - Environments - Internal & External - Especially Critical

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STPSS Panel on Development, Manufacturing, and Certification

Historical Problem Areas–Lessons Learned for Spacecraft Propulsion Systems

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June 25–29, 1990

Historical Problem Areas and Lessons Learned for Space Propulsion Systems

Applications

- Upper stages
- Orbit maneuvering and/or space transfer vehicles
- Low-earth-orbit spacecraft
- High-altitude satellites
- Planetary exploration spacecraft

Typical mission level propulsion requirements

- Attitude control/momentum management
- Orbit adjust/drag make up
- Stationkeeping
- Perigee/apogee orbit injection

Typical Space Propulsion Systems Currently in Use

Earth storable bipropellant

Monopropellant hydrazine

Cold gas

Solid kick motors

What Are the Issues?

Many problems keep recurring on operational systems

Lacking discipline and organized methodology to get full benefits from past lessons learned

Too much money spent on paper studies and associated processes

No enough money spent on propulsion system/device certification through realistic testing

Experience keeps telling us to validate design over full range of operating conditions

Need to demonstrate adequate margins

Need to conduct adequate test programs that validate:

- Selection of materials and processes
- Full range of realistic operating conditions (temperatures, pressures flow rates, mixture ratio, pressurant gas saturation, etc.)
- Design margins and robustness over range of potential operating conditions

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What Are the Issues? (Continued)

Must address issue of the cost of adequate testing during early development versus cost of solving problems later in certification cycle

Assessment of analysis and simulation versus testing: what is proper mix and how to make these efforts more complementary

Concentrate on fewer but higher quality technology and development programs

How can NASA and their supporting contractors make better use of test beds to address common recurring problems?

Examples abound of many unresolved recurring issues (e.g., adiabatic compression detonation, leakage, thermal control, inadequate materials, fracture mechanics, earth storable propellants residue buildup, etc.)

Historical Problems–Lessons That Should Have Been Learned

General problem areas

Materials compatibility

- Propellant chemical compatibility with storage and feed system materials
- Hot gas materials compatibility with thrust chambers, injectors, valves, etc.

Contamination problems

- Residue accumulation in earth storable (N_2O_4, MMH, and N_2H_4)
- Particulate and NVR buildup
- Wear debris contamination (valves, regulators, etc.)

Pneumatic/feed system flow instabilities leading to fatigue and premature component wear out

Other system instabilities

- Combustion (rocket engine)
- Thermal
- Fuel slosh (impact on vehicle dynamics)

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Some Examples of Lessons Learned From Past Spacecraft Propulsion System Problems

Problem	System Type	Examples From Past Programs	Solution
N_2H_4 and earth storable residue accumulation and associated flow decay	Monopropellant N_2H_4 N_2H_4/MMH	INTELSAT IV, P-95, ATS-V1, Gemini, Symphonie, Space Shuttle	Minimum propellant exposure during ground/test operations, cleanliness control, thermal conditioning and careful selection of materials
Shell 405 catalyst breakup	N_2H_4	P-95, Classified spacecraft	Catalyst bed/reactor design, heated catalyst beds
Hot restart sensitivity (potentially destructive worst-case thermal duty cycles)	N_2H_4, N_2O_4/MMH	INTELSAT-IV, Galileo, TDRS	Improved engine thermal design, higher operating margins and proper thermal installation
Freeze-thaw damage	N_2H_4 and N_2O_4	ATS-VI, Classified flight spacecraft failure	Redundant heaters/controls

Some Examples of Lessons Learned From Past Spacecraft Propulsion System Problems (Continued)

Problem	System Type	Examples From Past Programs	Solution
Catalyst bed self-poisoning	N_2H_4	P-95, Voyager, FLTSATCOM, DSP	Catalyst bed heaters and purified (analine-free) N_2H_4
Thruster nitriding and/or high temperature corrosion	N_2H_4, N_2H_4/MMH	DSCS-III, Space Shuttle APU, Gemini	Use more compatible materials and protective coatings
Plugging of injector feed tubes/valves with catalyst fines	N_2H_4	INTELSAT-III, Voyager	Injector orientation during dynamic excitation
Fuel slosh destabilization	All liquids	TACSATCOM, INTELSAT-IV, INSAT	Better total dynamic characterization of spacecraft under all realistic conditions

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Some Examples of Lessons Learned From Past Spacecraft Propulsion System Problems (Continued)

Problem	System Type	Examples From Past Programs	Solution
Combustion instabilities	All rockets	F-1, Titan, Atlas, Galileo, Apollo, Minuteman, Space Shuttle, etc.	Analyses and extensive characterization/validation test programs. Design modifications (feed system, baffles, acoustic cavities, resonators, etc.) as required
Exhaust plume interference	All rockets	SATCOM, Voyager	More accurate analyses and test to locate thrusters in safe/acceptable orientation
Composite rocket nozzle failure	Solid rocket motor nozzles	PAM-D motors on Westar and Palapa	Better testing (more comprehensive) and better materials
Thruster instabilities and thermal runaway	N_2O_4/MMH	Galileo, INTELSAT-VI, MILSTAR, INSAT, Mars Observer	More realistic test characterization and better design

Some Examples of Lessons Learned From Past Spacecraft Propulsion System Problems (Continued)

Problem	System Type	Examples From Past Programs	Solution
Improper operation on-orbit by ground controllers leads to failure	N_2O_4/MMH	INSAT-1A, INTELSAT-VI, many other flight spacecraft	More rigorous flight operations procedures and controls
Component failures on-orbit	N_2O_4/MMH, N_2H_4, cold gas, vaporizing NH_3	Mariner, Viking, Ariane, Centaur, Gemini, Apollo, FLTSATCOM, etc.	Redundant components with switching logic. Simpler system design with less components (e.g., blowdown pressurization)

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Near-Term and Future Spacecraft Propulsion System Concerns

Future mission requirements

- Single mission versus reusable designs (space basing)
- More complex environmental requirements for reusable systems–multiple launch and landings and space basing requirements
- Longer life times–mission reliability
- Use of composite propellant and pressurant storage vessels–fracture mechanics and determination of incipient failure thresholds for space based and reusable systems
- Micrometeroid and orbital debris protection of pressure vessels (space based reusable systems)
- Reliable nondestructive testing (NDE) on-orbit for space based long-life systems

Near-Term and Future Spacecraft Propulsion System Concerns (Continued)

Future mission requirements (continued)

- On-orbit repair and replacement including safe operations, logistics, spares provisioning, etc. on orbit
- On-orbit refueling
- Health monitoring and automatic fault detection/isolation and corrective action on orbit
- Development of new and better materials, coatings, processes, etc.

Future environmental impact concerns

- Need to assess realistic hazard levels and environmental impacts of earth storable propellants
- Relook at environmental impacts, life-cycle costs, and mission performance tradeoffs between solids, earth storable, space storable, and cryogenic propulsion systems for future spacecraft propulsion systems

Some Candidate Programs

Develop standards to resolve lingering and costly issues identified in past lessons learned

Characterize and develop higher energy space storable propulsion systems

Extensive life and margin mapping tests for new development items

Develop space basing technologies

- On-orbit refueling
- Repair and refurbishment logistics
- Establish some reusability limits

Some Candidate Programs (Continued)

Develop high strength, light weight composite tanks

Develop advanced high temperature thrust chamber and rotating machinery materials and coatings

Develop reliable simple on-orbit propellant gauging

Establish reliable repeatable on-orbit NDE techniques for pressure vessels

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Concluding Remarks

Concentrate funding where it does the most good for solving technology issues and the real hardware design problems

There really are plenty of lessons that have been learned from past problems

Need to generate and provide better data base of past lessons learned

More NASA-industry team work will help identify and resolve the recurring problems

Earlier and more comprehensive test programs to resolve recurring problems and address the newer requirements